



A DELTA RENEWED

A guide to science-based ecological restoration in the Delta

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Authors

LETITIA GRENIER
ROBIN GROSSINGER
JULIE BEAGLE
APRIL ROBINSON
SAM SAFRAN

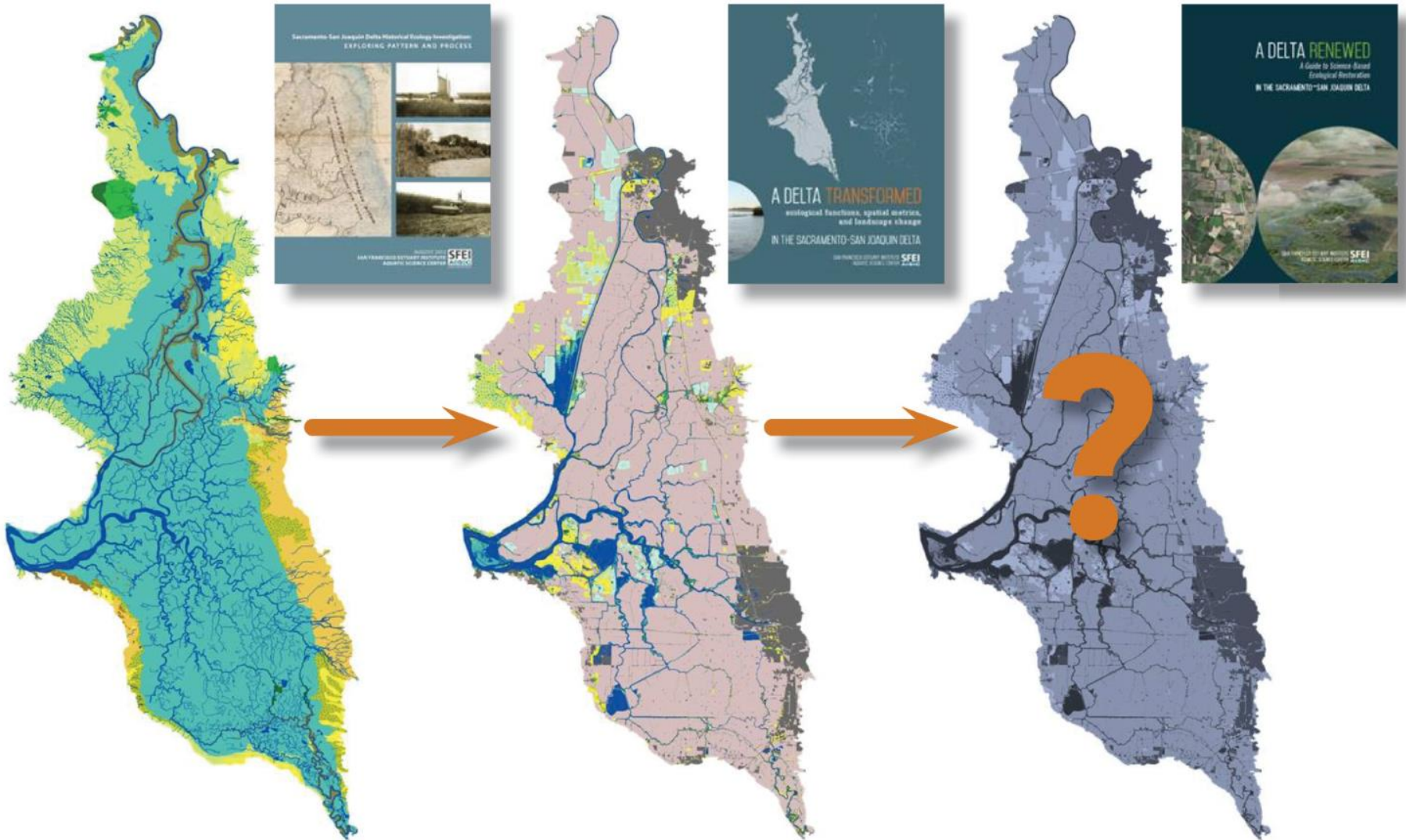
Presented to

DELTA PLAN
INTERAGENCY
IMPLEMENTATION
COMMITTEE
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THE ECOSYSTEM
RESTORATION
PROGRAM

How do we create a desirable, healthy ecosystem IN THE FUTURE DELTA?



"Restore **large areas** of **interconnected habitats** within the Delta and its watershed by 2100..."

—WATER CODE SECTION 85302

"Management plans and decisions need to be informed by a **landscape perspective** that recognizes interrelationships among patterns of land and water use, patch size, location and connectivity, and species success."

—DELTA PLAN

"We propose that science that encompasses the multiple, interacting components of functional landscapes in the Delta will **foster resilient and enduring restoration and management outcomes that benefit both people and wildlife.**"

WIENS ET AL., THE STATE OF BAY-DELTA SCIENCE 2016

large areas interconnected habitats

landscape perspective

**foster resilient and enduring restoration and management
outcomes that benefit both people and wildlife**



California Delta, ca. 1800



California Delta, 2014

Image Landsat

Google earth

**LANDSCAPE
INTERPRETATION
TEAM
SCIENCE
ADVISORS**

Stephanie Carlson (UC Berkeley)

Jim Cloern (USGS)

Brian Collins (University of Washington)

Chris Enright (Delta Science Program)

Joseph Fleskes (USGS)

Geoffrey Geupel (Point Blue)

Todd Keeler-Wolf (CDFW)

William Lidicker (UC Berkeley)

Steve Lindley (NMFS)

Jeff Mount (UC Davis)

Peter Moyle (UC Davis)

Anke Mueller-Solger (USGS)

Eric Sanderson (Wildlife Conservation Society)

Dave Zezulak (CDFW)

| LEVEL | POPULATION | | | | | | COMMUNITY | |
|-------|--|--|---|---|--|--|--|--|
| | Life-history support | | | | | Adaptation potential | Food webs | Biodiversity |
| | FUNCTION | FUNCTION | FUNCTION | FUNCTION | FUNCTION | FUNCTION | FUNCTION | FUNCTION |
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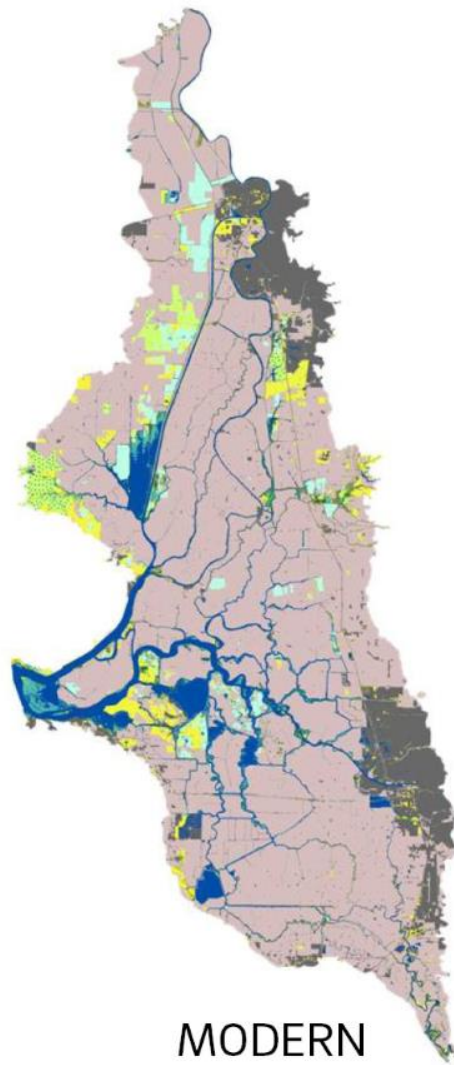
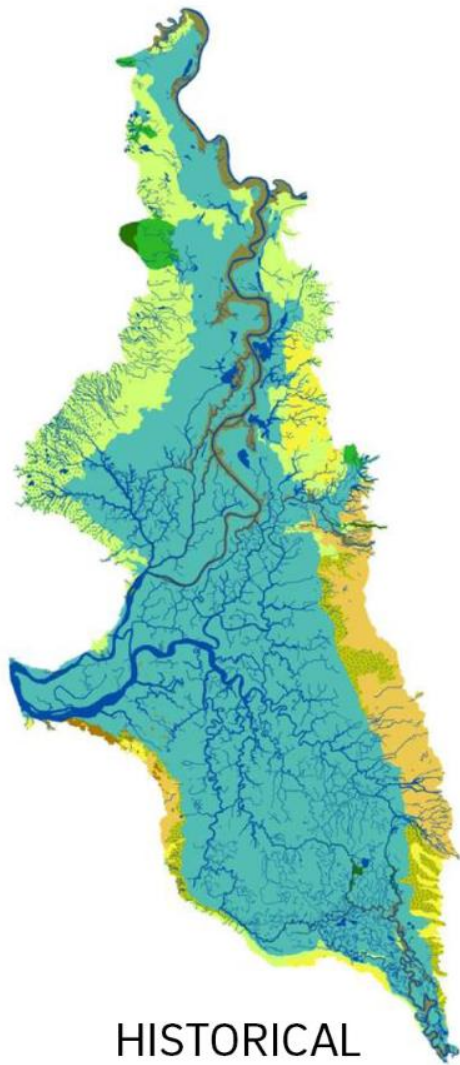
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| | Marsh to open water ratio | Marsh area by nearest neighbor distance | Wetted area by type in winter | Riparian habitat length by width class | | | | |
| | Adjacency of marsh to open water by length and marsh patch size | Marsh core area ratio | | | | | | |
| | Ratio of looped to dendritic channels | Marsh fragmentation index | | | | | | |
| METRICS | | | | | | | | |

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EXAMPLES OF METRICS:

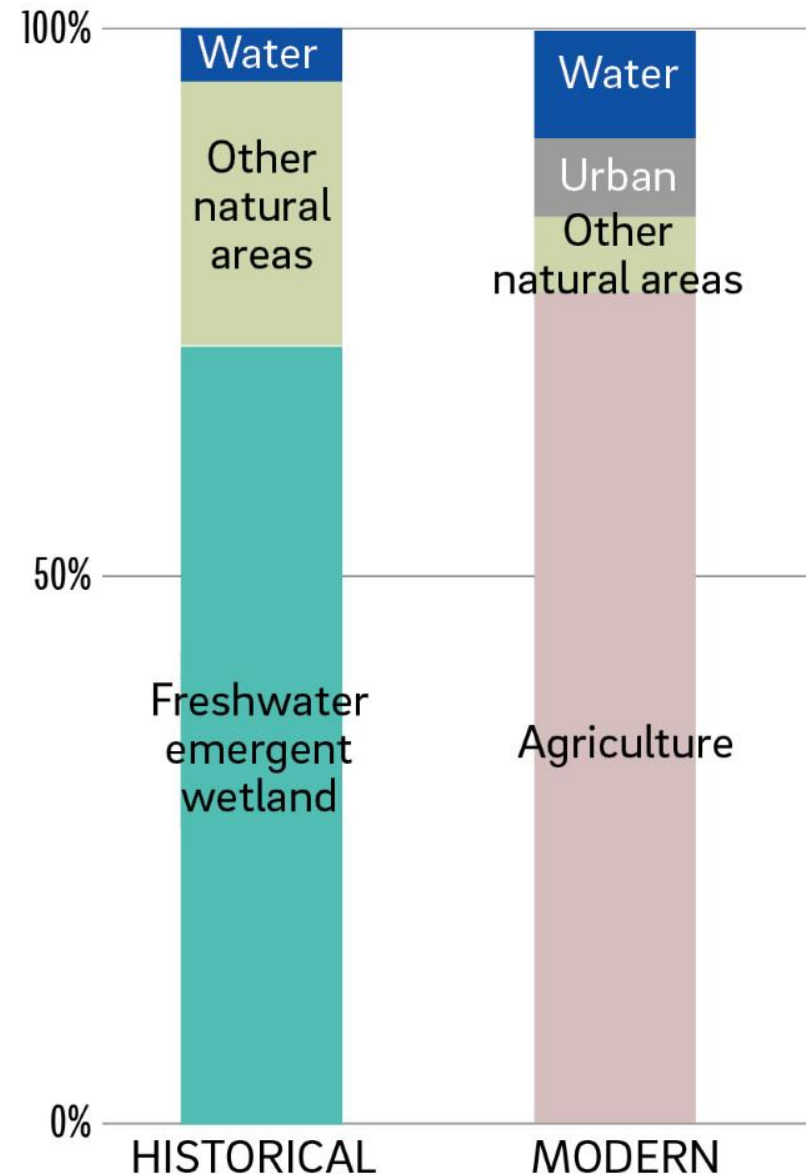
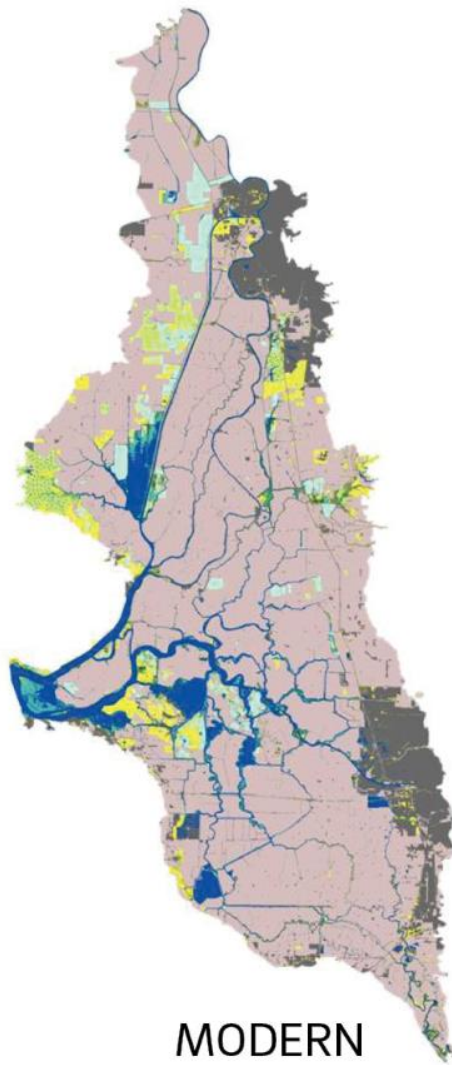
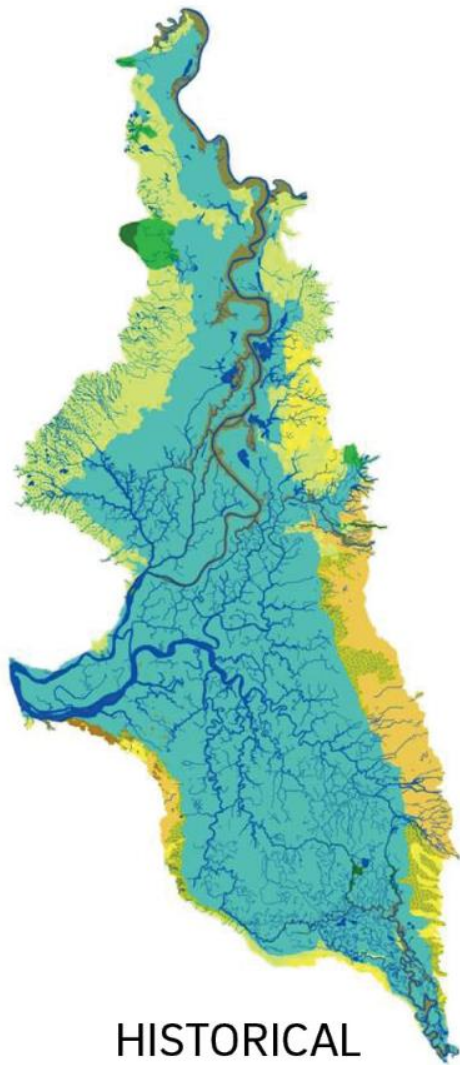
- Inundation extent
- Marsh patch size
- Distance to nearest large marsh
- Woody riparian patch size
- Marsh to open water ratio

Comparing historical land types to modern

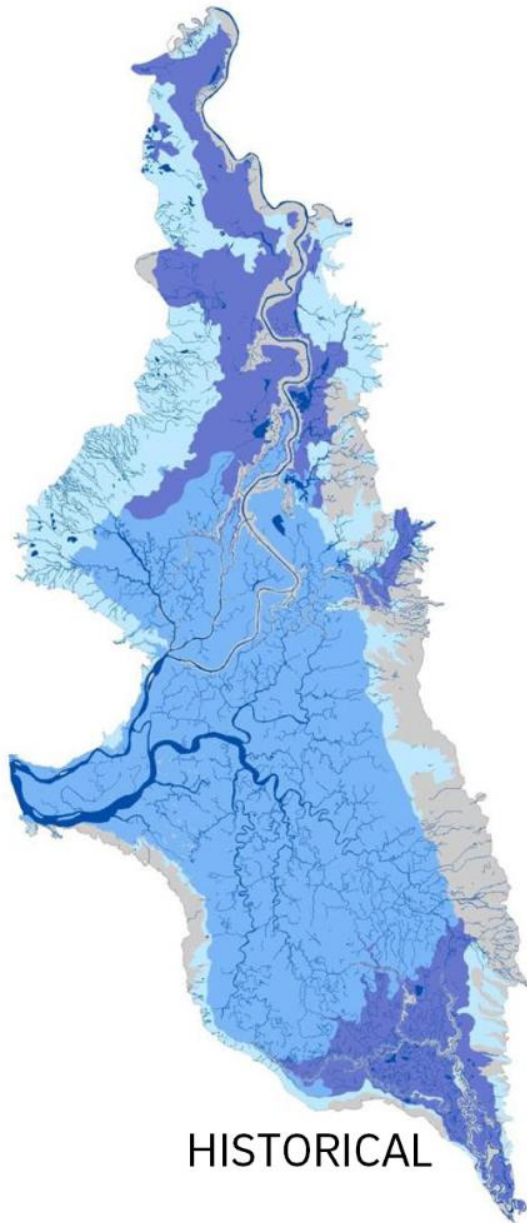


- Agriculture
- Urban/Barren
- Oak woodland/Savanna
- Grassland
- Stabilized interior dune vegetation
- Alkali seasonal wetland complex
- Vernal pool complex
- Wet meadow/Seasonal wetland
- Valley foothill riparian
- Willow
- Freshwater emergent wetland
- Water

Comparing historical land types to modern



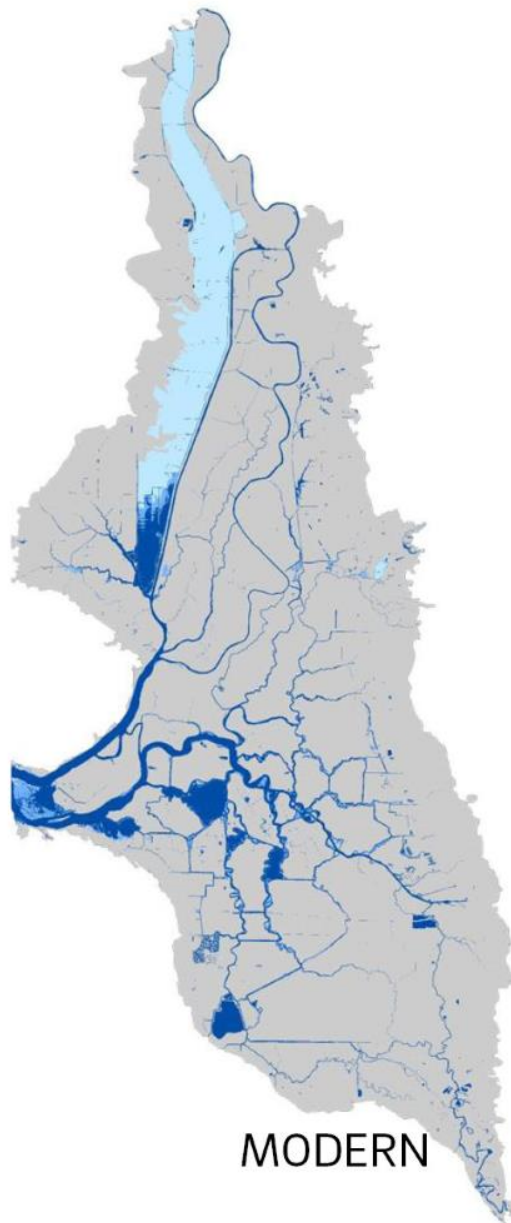
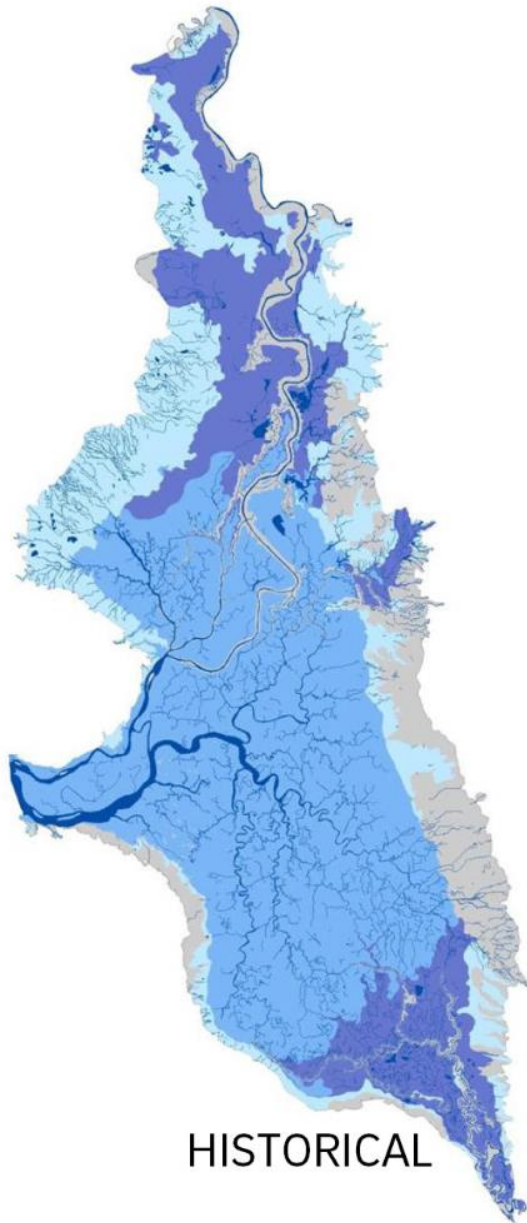
Comparing historical flooding to modern



HISTORICAL

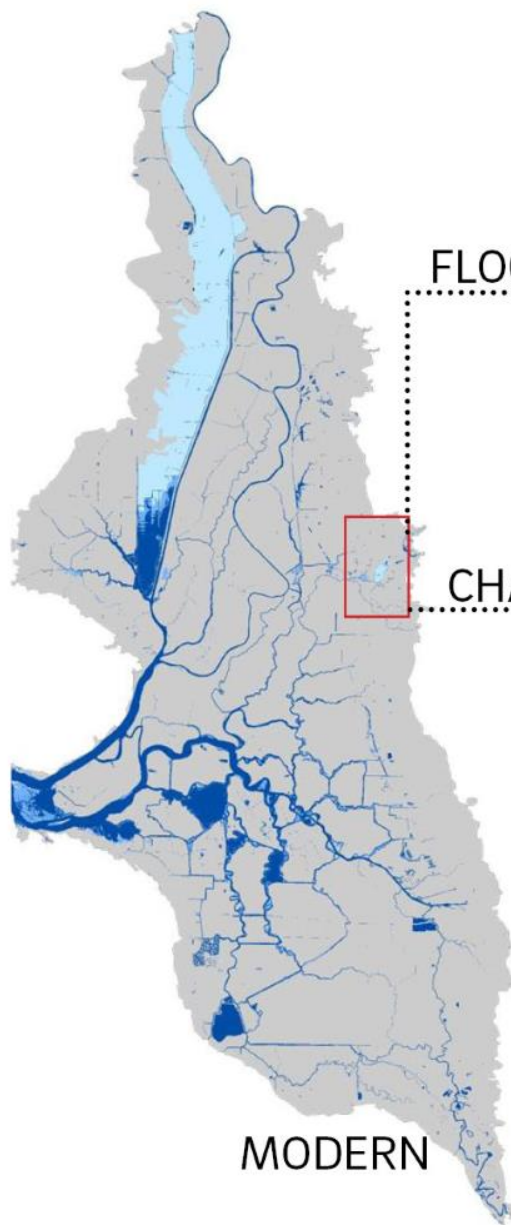
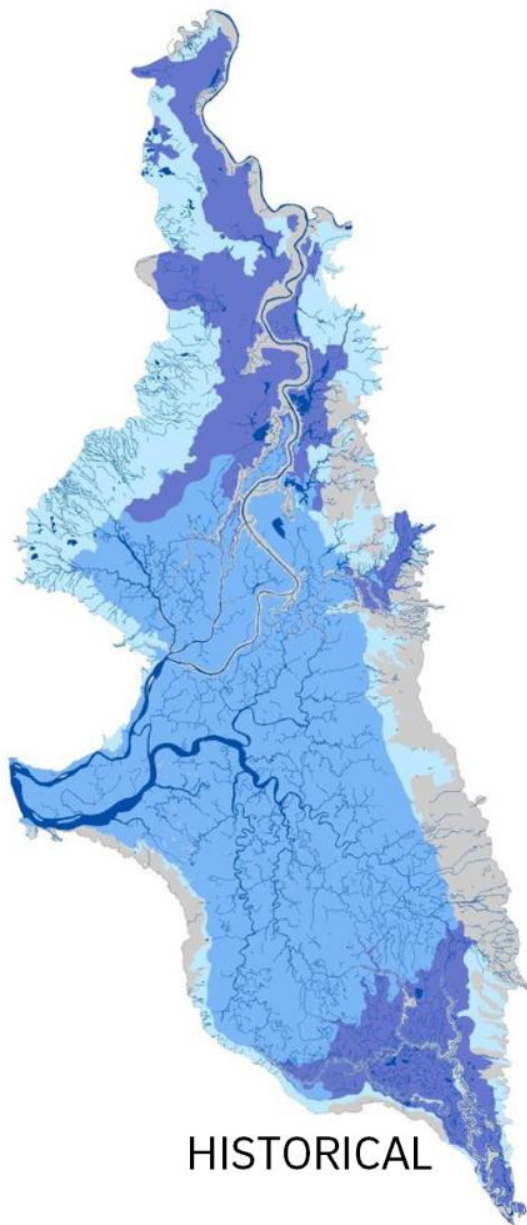
- Ponds, lakes, channels, flooded islands
- Tidal inundation
- Seasonal long duration flooding
- Seasonal short-term flooding

Comparing historical flooding to modern



- Ponds, lakes, channels, flooded islands
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Comparing historical flooding to modern



FLOODPLAIN

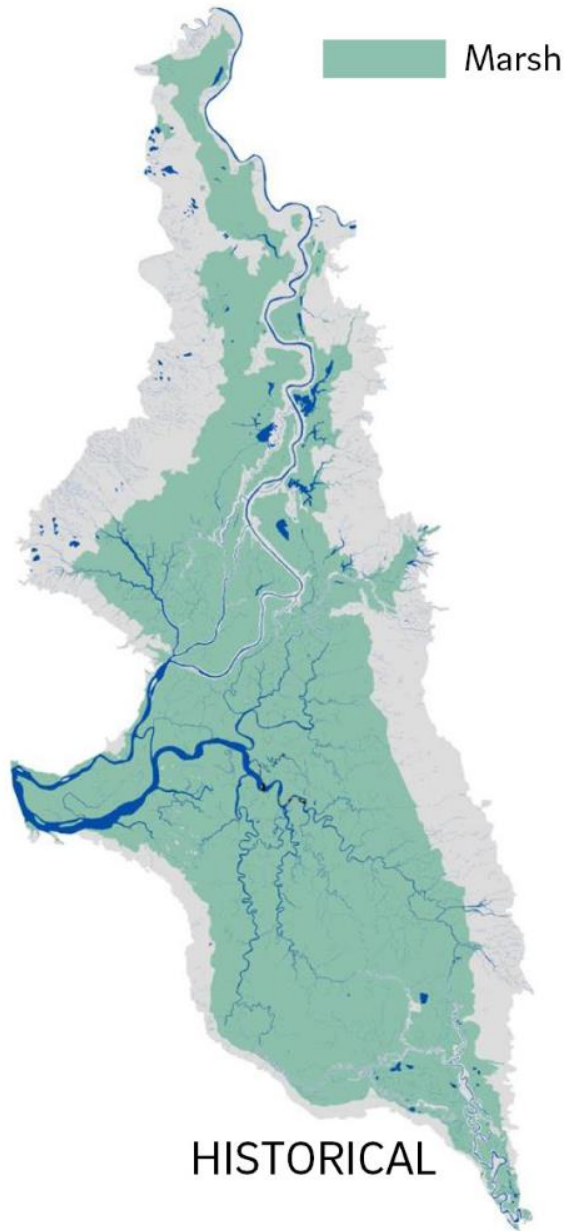
CHANNEL



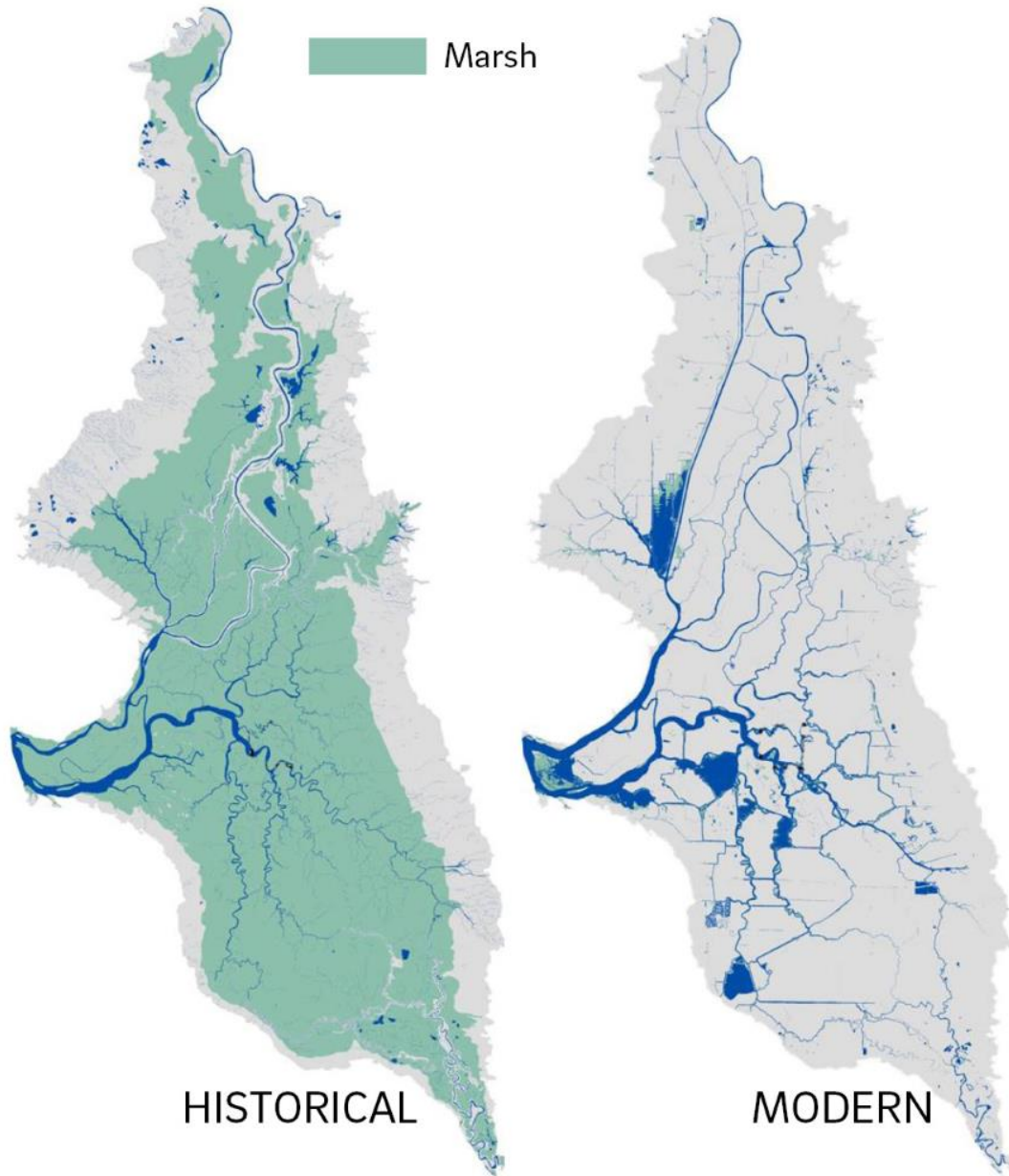
Photos courtesy of Jeff Opperman

- Ponds, lakes, channels, flooded islands
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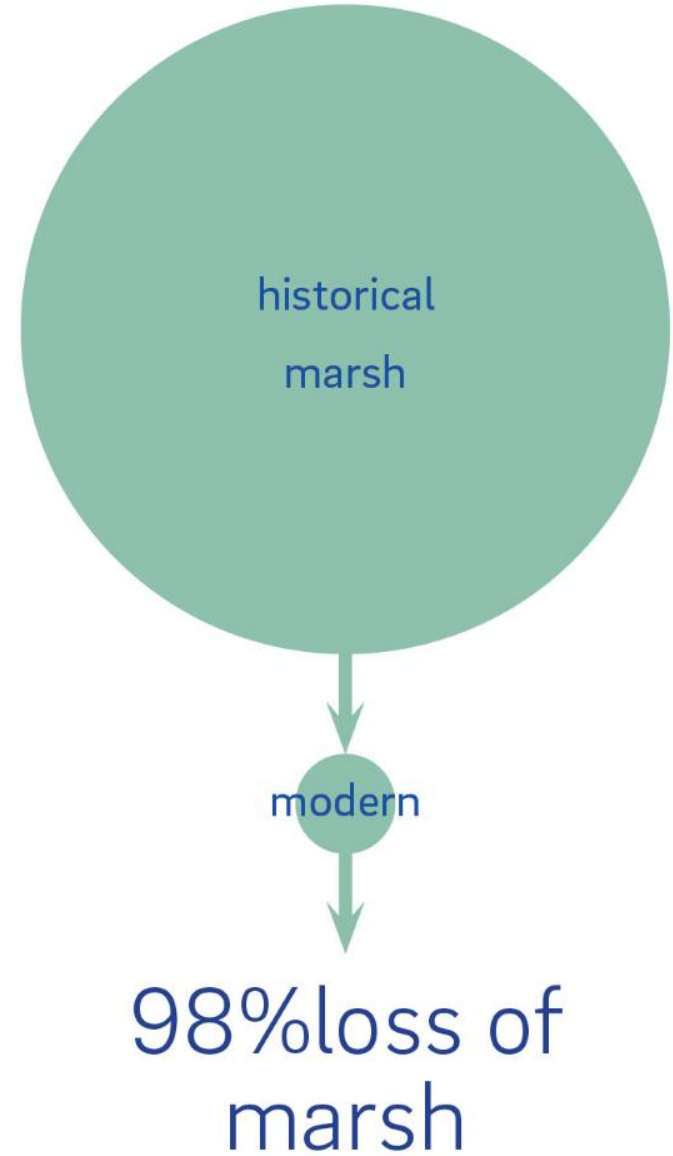
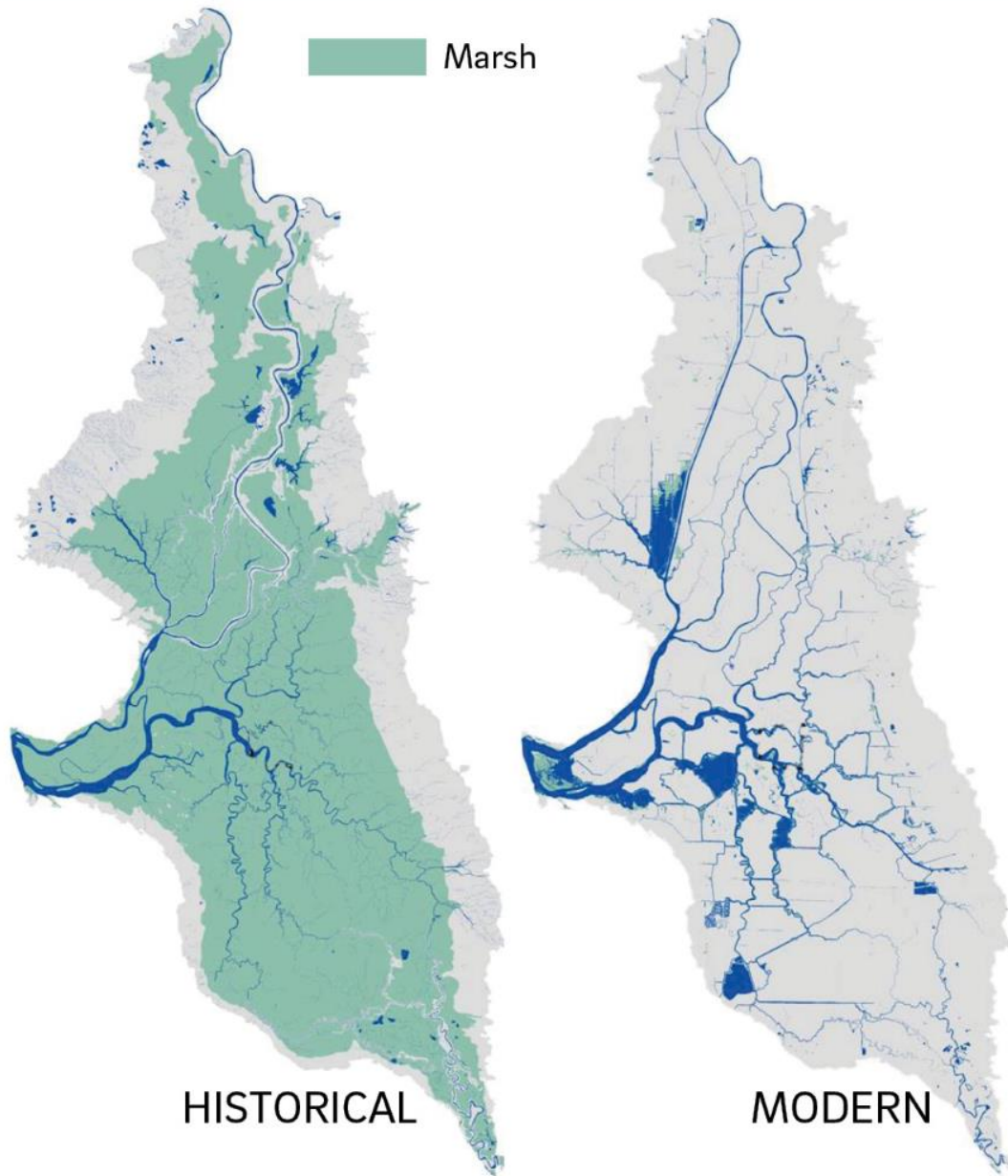
Comparing historical marsh to modern



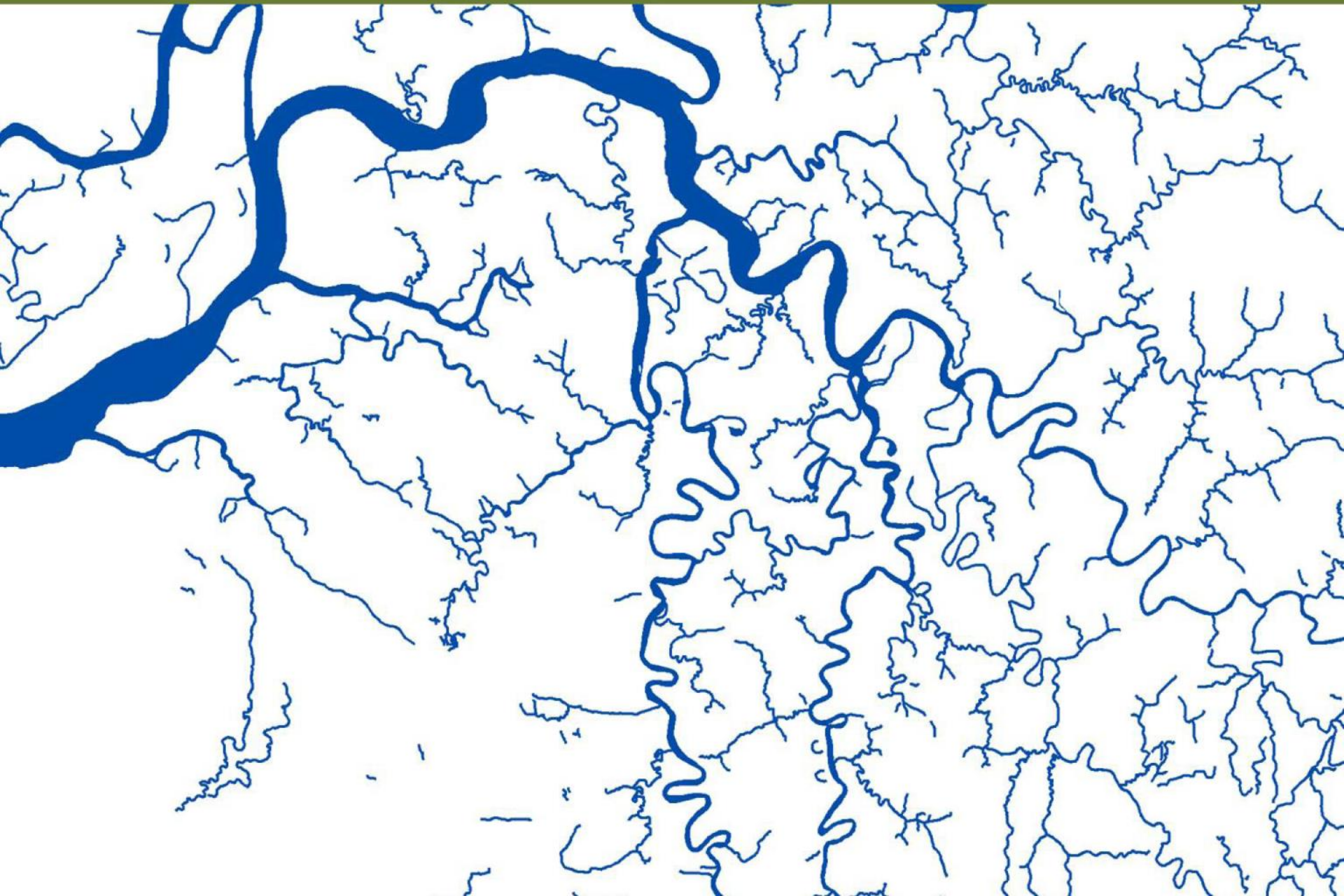
Comparing historical marsh to modern



Comparing historical marsh to modern



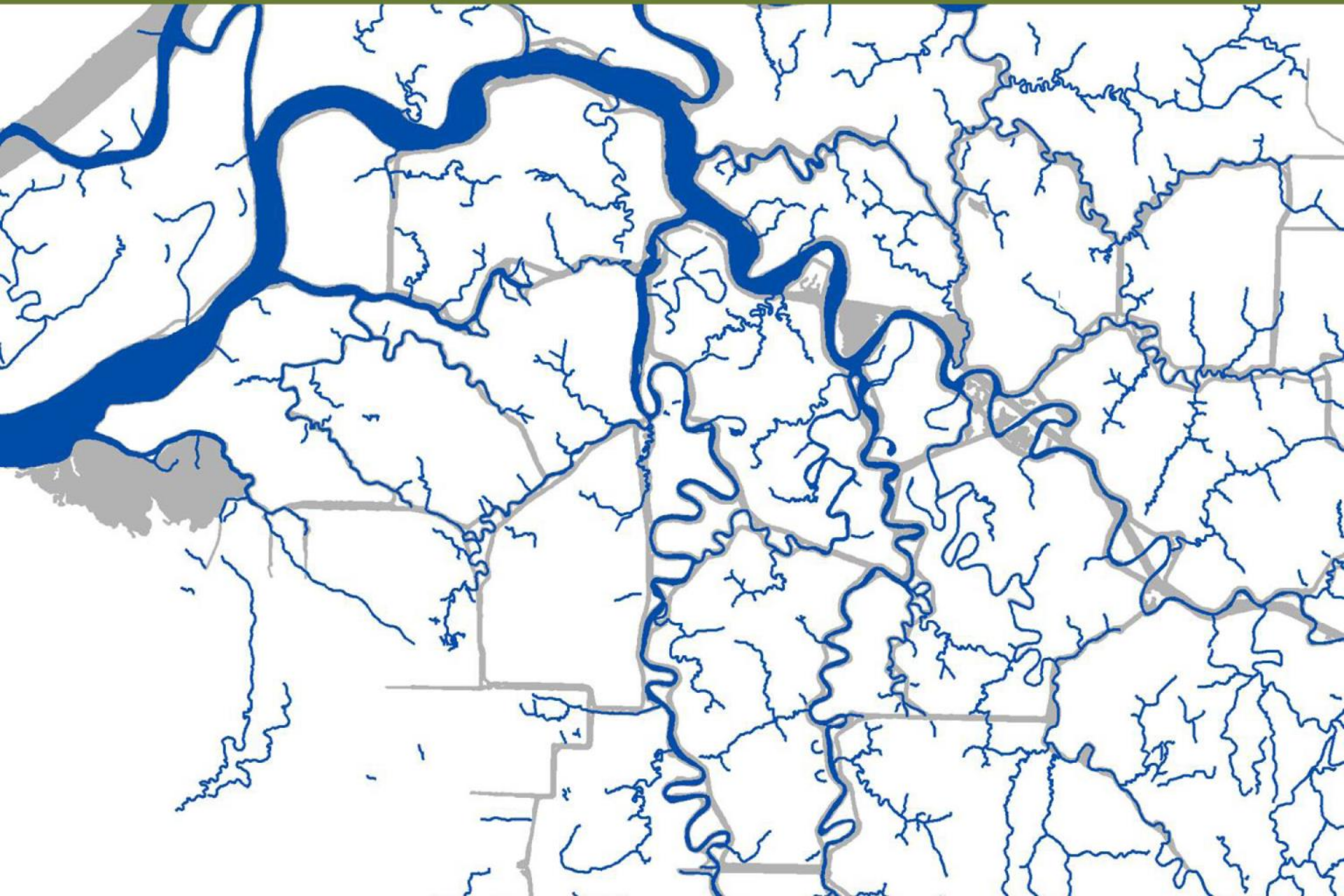
Comparing historical channels to modern



Comparing historical channels to modern



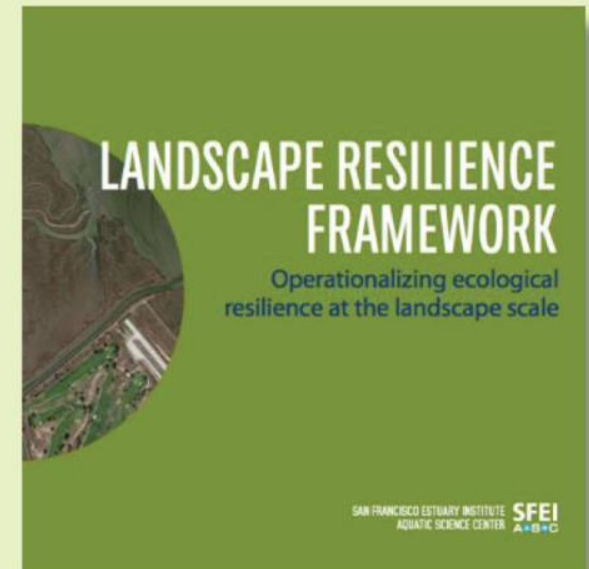
Comparing historical channels to modern



Comparing historical channels to modern

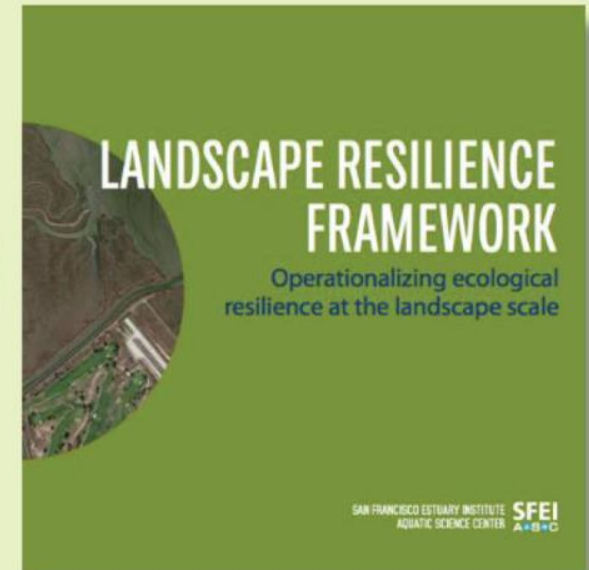


LANDSCAPE RESILIENCE FRAMEWORK



Beller E, Spotswood E, Robinson A, Anderson M, Grenier L, Grossinger R, Higgs E, Hobbs R, Suding K, Zavaleta E. in prep.

LANDSCAPE RESILIENCE FRAMEWORK



PHYSICAL PROCESSES



PHYSICAL PROCESSES



LANDSCAPE



PHYSICAL PROCESSES



LANDSCAPE



ECOLOGICAL FUNCTIONS

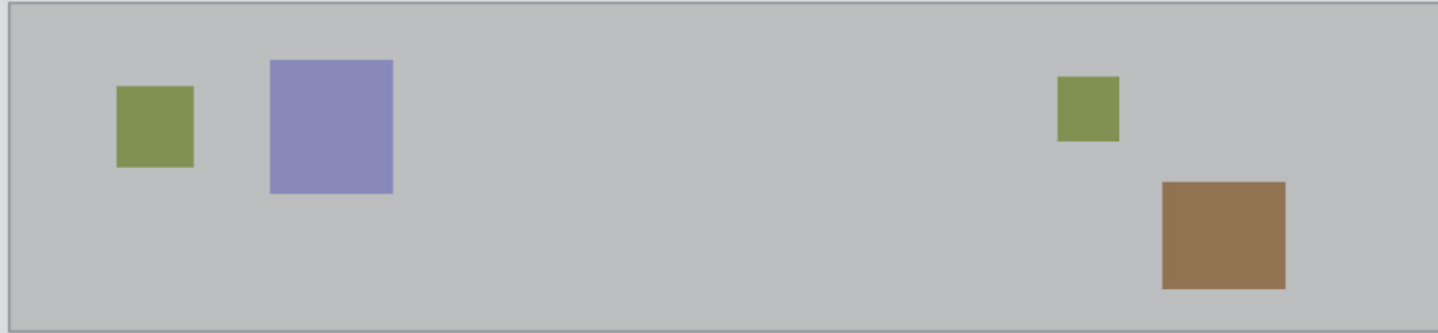
PHYSICAL PROCESSES

ECOLOGICAL FUNCTIONS

PHYSICAL PROCESSES

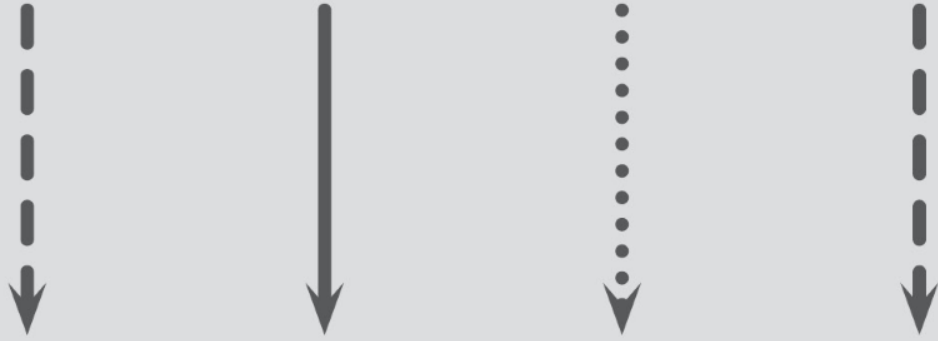


LANDSCAPE

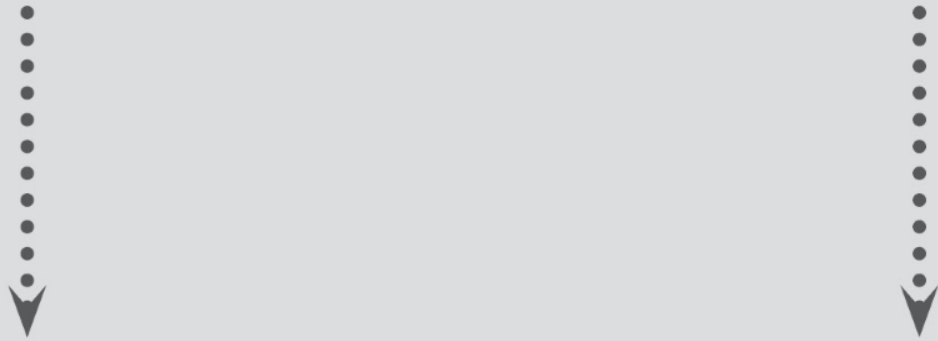
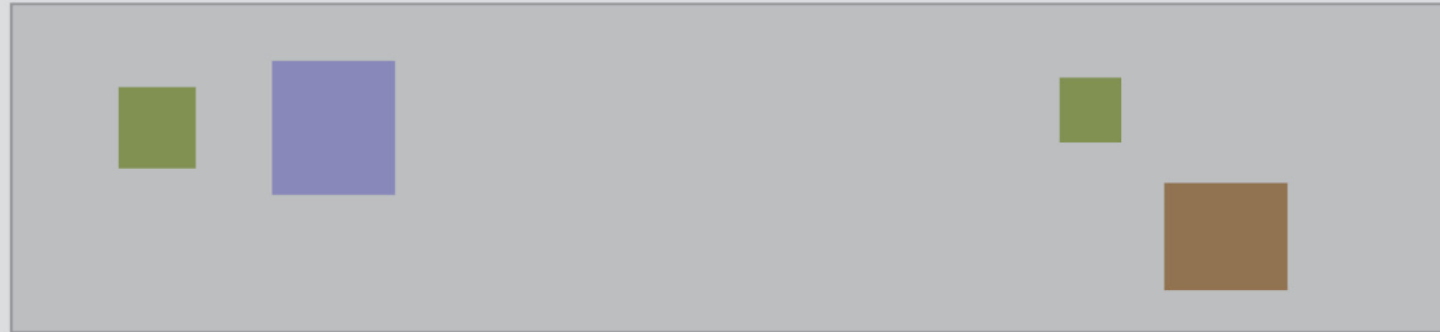


ECOLOGICAL FUNCTIONS

PHYSICAL PROCESSES

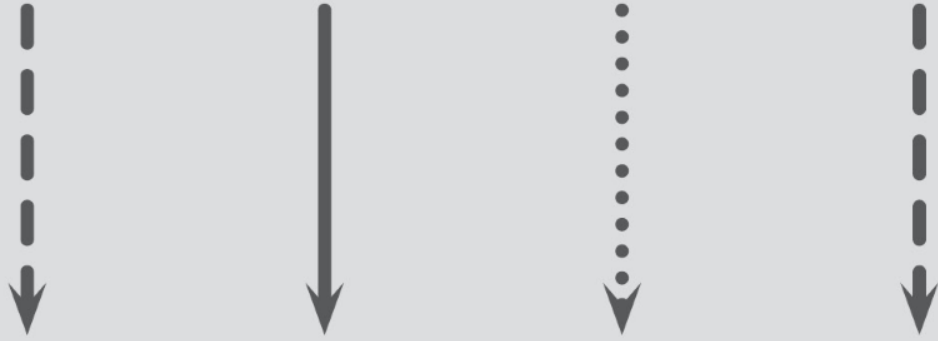


LANDSCAPE

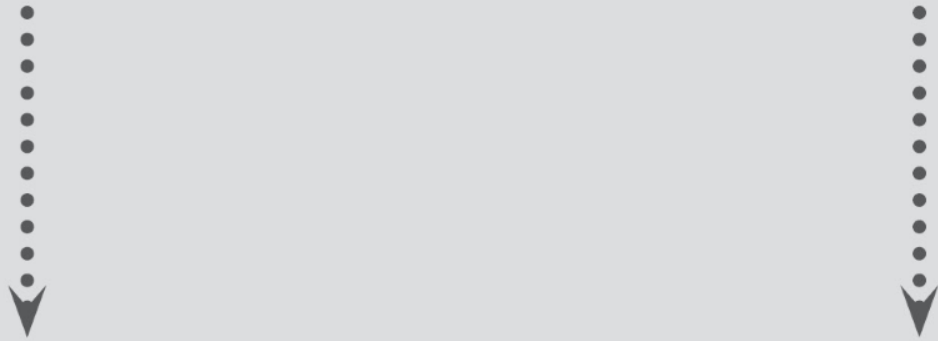


ECOLOGICAL FUNCTIONS

PHYSICAL PROCESSES



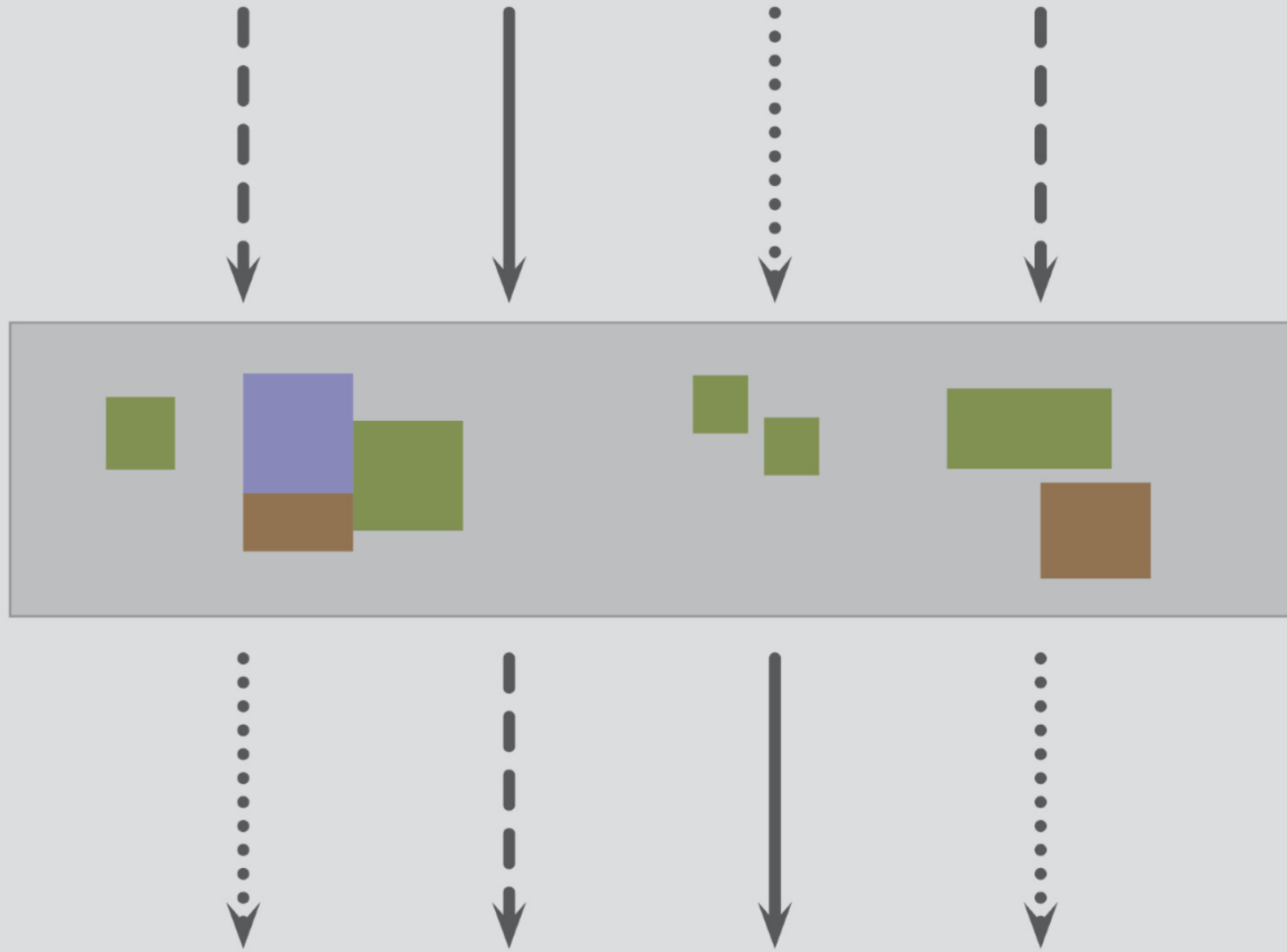
LANDSCAPE



ECOLOGICAL FUNCTIONS

PHYSICAL PROCESSES

LANDSCAPE

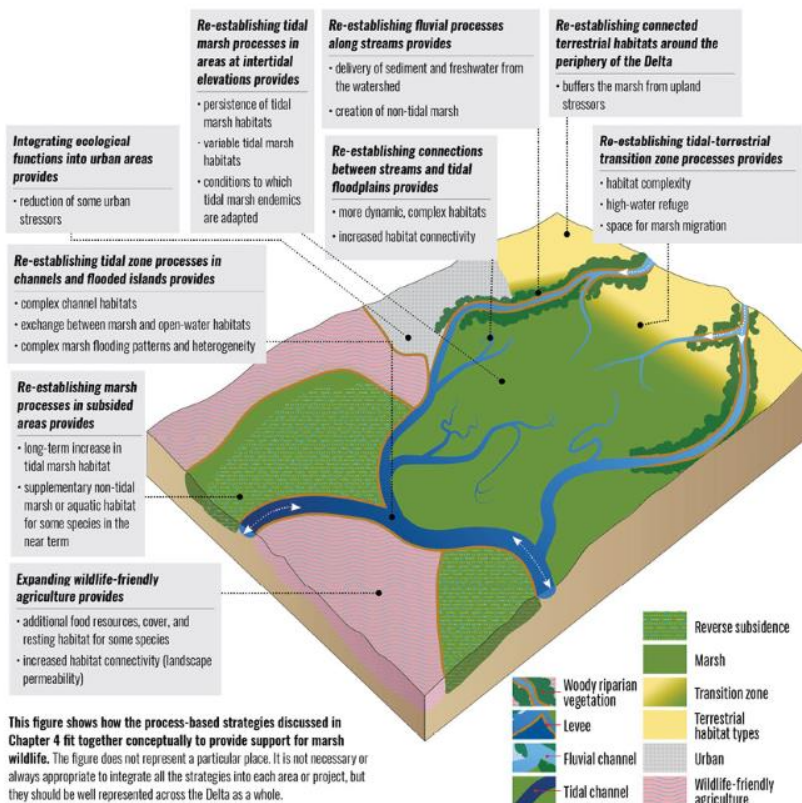


ECOLOGICAL FUNCTIONS: supporting marsh wildlife

(CONTINUED) marsh wildlife

How strategies fit together to support marsh wildlife

Restoring the tidal processes that create tidal marshes and the fluvial processes that support non-tidal marshes is vital to supporting marsh wildlife in the future Delta. Creating complete, complex systems will also require restoring appropriate transition-zone and terrestrial processes, often less considered in marsh restoration. Creating a coherent, integrated landscape that supports marsh wildlife will require us to strategically integrate marsh wildlife support into more developed lands, particularly agricultural areas. Integrating wildlife-friendly agriculture into landscape-scale planning could maximize benefits to wildlife.

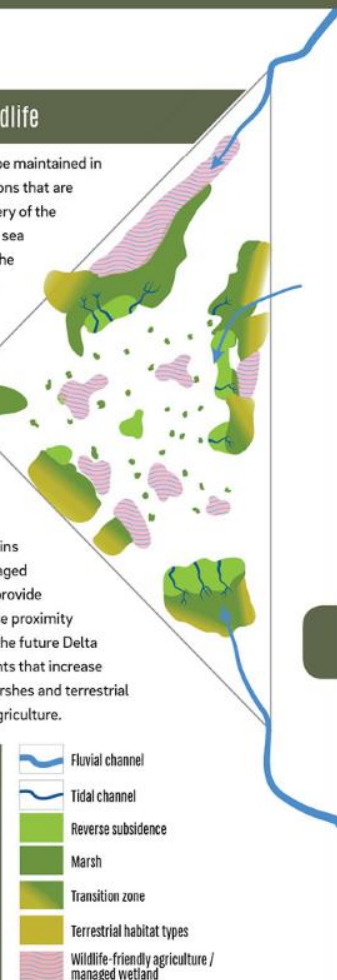


Potential landscape configuration to support marsh wildlife

Elevation is fundamental to determining where resilient marsh habitats can be maintained in the Delta, and therefore where marsh wildlife can best be supported. Elevations that are appropriate for supporting tidal marsh today exist primarily along the periphery of the Delta, with many of the islands in the Central Delta now subsided well below sea level. The largest extant marshes are in the West and Northwest Delta, and the widest expanses of land at intertidal elevation that could be restored to tidal action are in the North and South Delta. Inputs from the Sacramento and San Joaquin rivers could contribute sediment to support marsh accretion and habitat complexity. Additional opportunities exist in the East and Southwest Delta, where there are longer expanses of potentially restorable marsh with adjacent edge habitats to support a broad tidal-terrestrial T-zone. Areas upslope of current intertidal elevations could be managed as non-tidal freshwater marshes, seasonal wetlands, or wildlife-friendly agriculture in the short term, and provide space for marsh migration as sea level rises. Restoring marshes across the Delta should lead to more diverse marsh habitats, with complex mosaics of tidal and non-tidal marshes in the South Delta, flood basins in the North Delta, and brackish marshes in the West Delta. Tule farms, managed seasonal wetlands, flooded agricultural fields, and other novel habitats that provide support to marsh wildlife, will likely provide the greatest benefit when in close proximity to established marshes at intertidal elevations. Large areas of tidal marsh in the future Delta are unlikely to be contiguous, so it is important to maintain landscape elements that increase connectivity between marsh patches, particularly smaller stepping stone marshes and terrestrial habitats that marsh wildlife can disperse across, including wildlife-friendly agriculture.

Major uncertainties and knowledge gaps

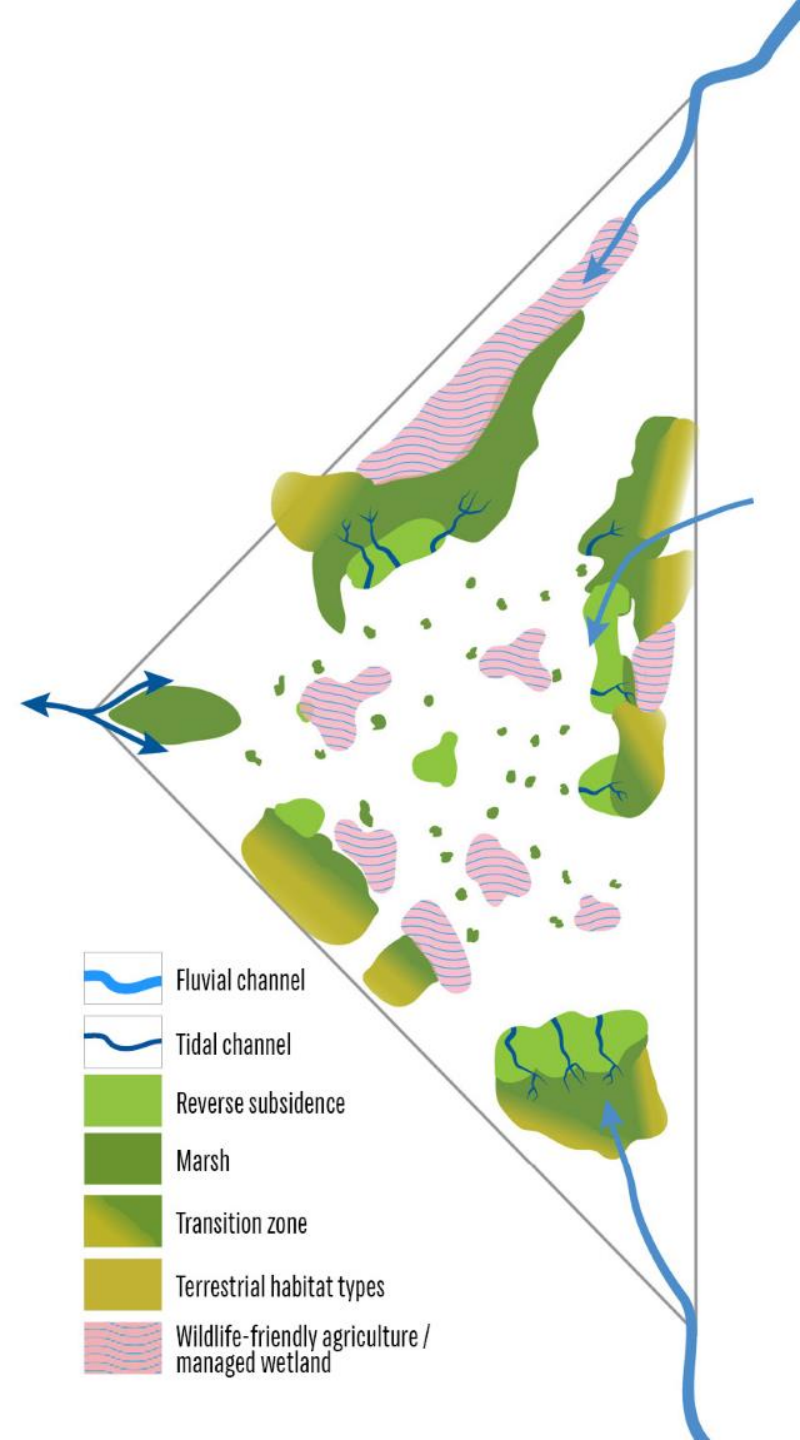
- **Projections for sea-level rise:** How will tidal range change with sea-level rise? Can we predict in detail how salinity gradients will change?
- **Sediment dynamics:** How much inorganic sediment supply is needed for extant and restored marshes to keep pace with sea-level rise, factoring in peat accumulation? How can sediment deposition in marshes be maximized (or subsidized with sediment from other sources)?
- **Effects of restoration or levee failure on tidal range:** How will opening up large areas of the Delta, particularly in the Central Delta, affect tidal energy in the rest of the Delta? How should restoration be phased or prioritized to balance the urgency of restoration due to sea-level rise with the need to maintain tidal range?
- **Marsh channel re-creation:** How do marsh channels initiate in Delta marsh restoration projects? How do we support formation of dendritic channel networks?
- **Marsh erosion:** How much of a problem is marsh erosion, and where is it happening? What interventions might minimize erosion?
- **Effects of new invasive species:** Which interventions might minimize new invasions?



This conceptual map shows a hypothetical configuration to illustrate how some of the strategies and recommendations might play out at the full Delta scale to support resilient marsh wildlife populations.

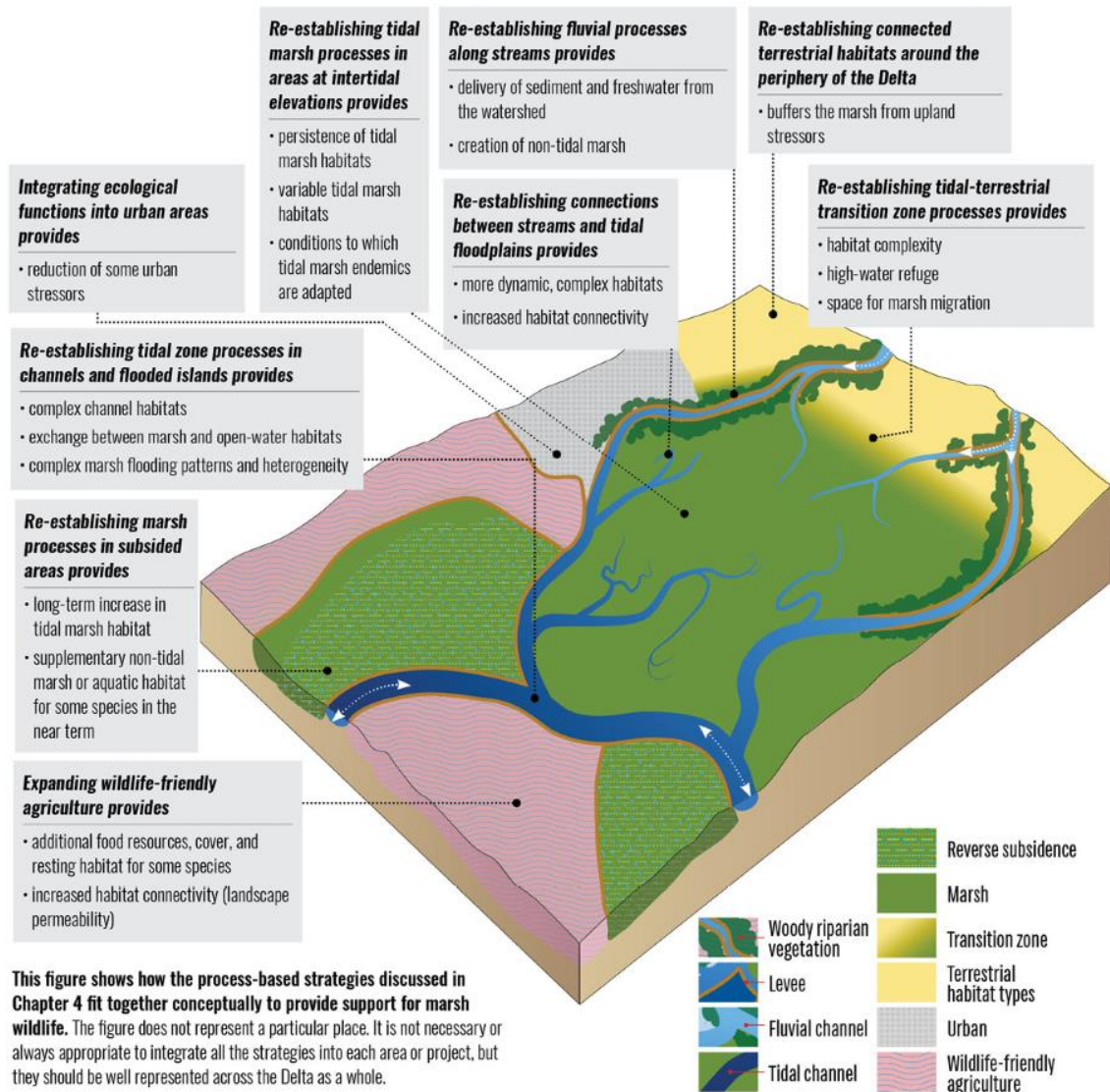
ECOLOGICAL FUNCTIONS: supporting marsh wildlife

Potential landscape configuration



ECOLOGICAL FUNCTIONS: supporting marsh wildlife

How strategies fit together



PROCESS-BASED STRATEGIES re-establish tidal processes

RESTORE TIDAL ZONE PROCESSES

Re-establish tidal marsh processes in areas at intertidal elevations

SUPPORTED FUNCTIONS

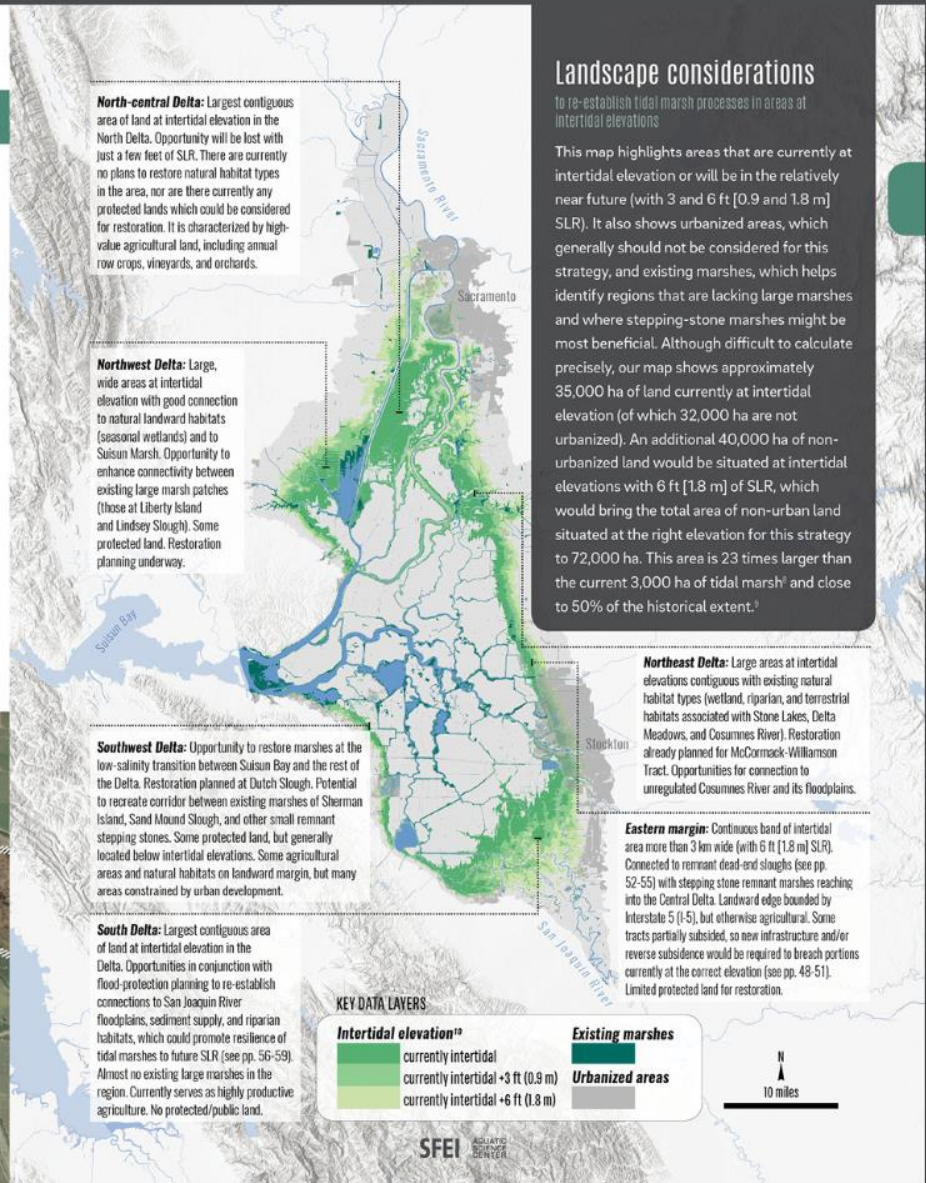


Large swaths of land in the Delta currently are situated at intertidal elevations but are separated from the tides by levees and other human infrastructure. These areas have the greatest potential to support tidal marshes with minimal management intervention now and into the future because, if connected to tidal action, they would be inundated at a depth and frequency that is appropriate for the establishment and persistence of emergent marsh vegetation. The ebb and flow of the tides across intertidal areas would allow for processes—like sediment deposition, scour, and flooding—that are needed to create channel networks, ponded areas, natural levees, and other important marsh features.

The areas at intertidal elevation are not static. With continued sea-level rise (SLR), these areas will shift. This process generates opportunities to restore tidal marshes in new (landward) areas in the future, but also increases the urgency to restore the areas that are currently intertidal, while their elevation is still favorable. More research is needed to understand the trade-offs that accompany large tidal marsh restoration. One concern is that an increase in the area of tidal marsh could alter tidal range in other parts of the Delta, with cascading effects that are difficult to predict.

Specific tactics for carrying out this strategy include: connecting lands in intertidal areas to tidal action by removing or breaching levees; removing other barriers to the exchange of water and sediment across marsh surfaces; and preventing the erosion of marsh edges using wind/wave energy breaks and other shoreline stabilization structures (both living and non-living). Many of these tactics will require active management using tide gates and water-control structures.

Image courtesy Google



PROCESS-BASED STRATEGIES

re-establish tidal processes

North-central Delta: Largest contiguous area of land at intertidal elevation in the North Delta. Opportunity will be lost with just a few feet of SLR. There are currently no plans to restore natural habitat types in the area, nor are there currently any protected lands which could be considered for restoration. It is characterized by high-value agricultural land, including annual row crops, vineyards, and orchards.

Northwest Delta: Large, wide areas at intertidal elevation with good connection to natural landward habitats (seasonal wetlands) and to Suisun Marsh. Opportunity to enhance connectivity between existing large marsh patches (those at Liberty Island and Lindsey Slough). Some protected land. Restoration planning underway.

Southwest Delta: Opportunity to restore marshes at the low-salinity transition between Suisun Bay and the rest of the Delta. Restoration planned at Dutch Slough. Potential to recreate corridor between existing marshes of Sherman Island, Sand Mound Slough, and other small remnant stepping stones. Some protected land, but generally located below intertidal elevations. Some agricultural areas and natural habitats on landward margin, but many areas constrained by urban development.

South Delta: Largest contiguous area of land at intertidal elevation in the Delta. Opportunities in conjunction with flood-protection planning to re-establish connections to San Joaquin River floodplains, sediment supply, and riparian habitats, which could promote resilience of tidal marshes to future SLR (see pp. 56-59). Almost no existing large marshes in the region. Currently serves as highly productive agriculture. No protected/public land.

Landscape considerations

to re-establish tidal marsh processes in areas at intertidal elevations

This map highlights areas that are currently at intertidal elevation or will be in the relatively near future (with 3 and 6 ft [0.9 and 1.8 m] SLR). It also shows urbanized areas, which generally should not be considered for this strategy, and existing marshes, which helps identify regions that are lacking large marshes and where stepping-stone marshes might be most beneficial. Although difficult to calculate precisely, our map shows approximately 35,000 ha of land currently at intertidal elevation (of which 32,000 ha are not urbanized). An additional 40,000 ha of non-urbanized land would be situated at intertidal elevations with 6 ft [1.8 m] of SLR, which would bring the total area of non-urban land situated at the right elevation for this strategy to 72,000 ha. This area is 23 times larger than the current 3,000 ha of tidal marsh⁴ and close to 50% of the historical extent.⁵

Northeast Delta: Large areas at intertidal elevations contiguous with existing natural habitat types (wetland, riparian, and terrestrial habitats associated with Stone Lakes, Delta Meadows, and Cosumnes River). Restoration already planned for McCormack-Williamson Tract. Opportunities for connection to unregulated Cosumnes River and its floodplains.

Eastern margin: Continuous band of intertidal area more than 3 km wide (with 6 ft [1.8 m] SLR). Connected to remnant dead-end sloughs (see pp. 52-55) with stepping stone remnant marshes reaching into the Central Delta. Landward edge bounded by Interstate 5 (I-5), but otherwise agricultural. Some tracts partially subsided, so new infrastructure and/or reverse subsidence would be required to breach portions currently at the correct elevation (see pp. 48-51). Limited protected land for restoration.

KEY DATA LAYERS

Intertidal elevation^{1a}

currently intertidal
currently intertidal +3 ft (0.9 m)
currently intertidal +6 ft (1.8 m)

Existing marshes

Urbanized areas

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PROCESS-BASED STRATEGIES

guidelines for re-establishing tidal processes

RESTORE TIDAL ZONE PROCESSES

(CONTINUED) Intertidal elevations

PHYSICAL PROCESS GUIDELINES

1 Tidal marshes should experience full tidal action

Tidal flows should be sufficient to drive the flux of materials into and out of marshes. In particular, tidal flows should drive regular inundation of the marsh plain, which provides direct access to foraging by aquatic organisms, enhances the export of productivity from the marsh plain into the adjacent aquatic environment, plays a role in maintaining local water temperature gradients, and promotes marsh accretion (see Guideline #3 below). Tidal flows should also be sufficient to drive the formation and maintenance of dendritic channel networks, which increase habitat complexity and are critical to the use of marshes by many species.

2 Tidal marshes should have complex and variable patterns of tidal inundation

Marshes naturally exhibit complex patterns of inundation and drainage driven by the feedbacks between spring-neap variability in tidal range and microtopographic features. Lower high tides inundate the marsh plain from the tips of interior blind channels, while higher high tides inundate the marsh plain over small natural levees around its perimeter.¹¹ Ecosystem engineers, such as beaver and waterfowl, also alter the marsh surface and add to its spatial heterogeneity.¹² Variable inundation patterns drive fine-scale heterogeneity in environmental conditions (such as soil moisture and chemistry) and create different microhabitats for a range of plants and animals.

3 Tidal marshes should maintain processes that allow them to keep their extent over time

For more than 6,000 years, as sea level in the estuary steadily rose, the Delta's marshes maintained land-surface elevations slightly above local mean sea level. Multiple interrelated processes contributed to this homeostasis and allowed for the continuous existence of marshes over time, but of particular importance is the vertical accumulation of organic plant matter. Frequent inundation (tidal or fluvial) is critical to the accumulation of organic matter, since it helps maintain high water table levels that prevent the oxidation and decomposition of peat.¹³ Inundation also contributes to marsh accretion through 1) the delivery of suspended inorganic sediment, which contributes to peat formation, and 2) the delivery of nutrients, which promote plant growth and the accumulation of organic material.¹⁴

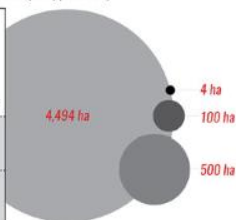
LANDSCAPE CONFIGURATION & SCALE GUIDELINES

4 Tidal marshes should be as large as possible

Though small marshes have some value, marshes should be as large as possible since the functions they support increase with size. For example, marshes as small as 1 ha can support some California Black Rails, but the density of rails is maximized once marshes reach approximately 100 ha in size. Blind channel length also increases disproportionately with marsh island area:²⁵ marshes larger than most that exist today are likely needed to maintain long, multi-order channel networks (see pp. 52-55).

Reference values

| | |
|------------|---|
| <1 ha | = 1 marsh patch size for Tricolored Blackbird nesting ²⁶ |
| 1 ha | = minimum marsh patch size for California Black Rail occupancy ²⁷ |
| 100 ha | = minimum marsh patch size for maximum Black Rail density ²⁸ |
| 500 ha | = approximate marsh area for a full channel network (based on historical landscape) ¹³ |
| 4,494 ha | = average historical patch size (SD = 17,956) ²⁹ |
| 4 ha | = average modern patch size (SD = 24) ³¹ |
| 110,527 ha | = maximum historical patch size ²² |
| 749 ha | = maximum modern patch size ³¹ |



5 Distance between tidal marshes should be minimized

Restoration plans should aim to decrease the nearest neighbor distance of Delta marshes and increase the proportion of marshes that occur in close proximity to large marshes. Marsh nearest neighbor distances should be informed by factors like animal dispersal distances. For example, because outmigrating juvenile salmon travel during the night and hold in low-velocity refugia habitats like marsh channels during the day,³⁴ they may benefit from gaps between marshes that are less than the distances they generally travel over a 24 hour period. Though historically the maximum distance between marshes was much less than this distance, today even the mean distance between marshes exceeds the mean distance smolts generally travel in a day.

| | |
|---------|---|
| 0.2 km | = median natal Song Sparrow dispersal distance (San Pablo Bay) ³⁵ |
| 5 km | = mean Black Rail dispersal distance ³⁶ |
| 15 km | = mean salmon smolt daily migration distance ³⁷ |
| 0.3 km | = mean historical distance from one marsh to a sizeable (100 ha) marsh (SD = 0.4) ³⁸ |
| 19.2 km | = mean modern distance from one marsh to a sizeable (100 ha) marsh (SD = 11.1) ³⁹ |
| 1.6 km | = maximum historical distance from one marsh to a sizeable (100 ha) marsh ³⁰ |
| 61.4 km | = maximum modern distance from one marsh to a sizeable (100 ha) marsh ³¹ |



6 The ratio of core to edge habitat should be maximized

Marsh patches should have more core habitat than edge habitat (excluding "interior" edges created by channel networks). Core areas experience distinct abiotic conditions, are less accessible to many predators of marsh wildlife, and are more buffered from human disturbance in the modern landscape. We would expect, for example, Black Rail presence to be more likely in patches with high core to edge ratios than those with low ratios.³²

| | |
|------|---|
| 13.1 | = historical marsh core:edge area ratio ³² |
| 0.2 | = modern marsh core:edge area ratio ³⁴ |

7 The ratio of marsh to open water should increase

Individual restoration projects should increase the landscape's marsh to open water ratio. Increasing the ratio would be expected to increase the availability of marsh-derived primary productivity to the aquatic food web. This is important since most large estuaries depend on detrital pathways to fuel the food web.²⁵ Research suggests that pools of particulate organic carbon (POC) in the aquatic environment will only reflect marsh inputs when total marsh area exceeds total open water area.³⁸

| | |
|------|--|
| 1.0 | = approximate minimum marsh : open water area ratio for marsh-derived carbon to be reflected in open water POC pools ³⁷ |
| 11.8 | = historical marsh open water area ratio ³⁸ |
| 0.2 | = modern marsh:open water area ratio ³⁹ |

8 Maximize tidal marsh-water edge length through the development of interior channel networks

Adjacency between marshes and open water habitats is required for many aquatic organisms to utilize and benefit from marshes. Increasing the length of adjacency through the fragmentation of existing marshes would be counterproductive (see Guideline #6 above). Adjacency should instead be increased by developing channel networks embedded within marshes (see pp. 52-55).

PROCESS-BASED STRATEGIES

guidelines for re-establishing tidal processes

LANDSCAPE CONFIGURATION & SCALE GUIDELINES

4

Tidal marshes should be as large as possible

Though small marshes have some value, marshes should be as large as possible since the functions they support increase with size. For example, marshes as small as 1 ha can support some California Black Rails, but the density of rails is maximized once marshes reach approximately 100 ha in size. Blind channel length also increases disproportionately with marsh island area;¹⁵ marshes larger than most that exist today are likely needed to maintain long, multi-order channel networks (see pp. 52-55).

Reference values

<1 ha = 1 marsh patch size for Tricolored Blackbird nesting¹⁶

1 ha = minimum marsh patch size for California Black Rail occupancy¹⁷

100 ha = minimum marsh patch size for maximum Black Rail density¹⁸

500 ha = approximate marsh area for a full channel network (based on historical landscape)¹⁹

4,494 ha = average **historical** patch size (SD = 17,956)²⁰

4 ha = average **modern** patch size (SD = 24)²¹

110,527 ha = maximum **historical** patch size²²

749 ha = maximum **modern** patch size²³

PROCESS-BASED STRATEGIES

guidelines for re-establishing tidal processes

LANDSCAPE CONFIGURATION SCALE GUIDELINES

4

Tidal

4,494 ha =
average historical
marsh patch size

4 ha = average modern
marsh patch size

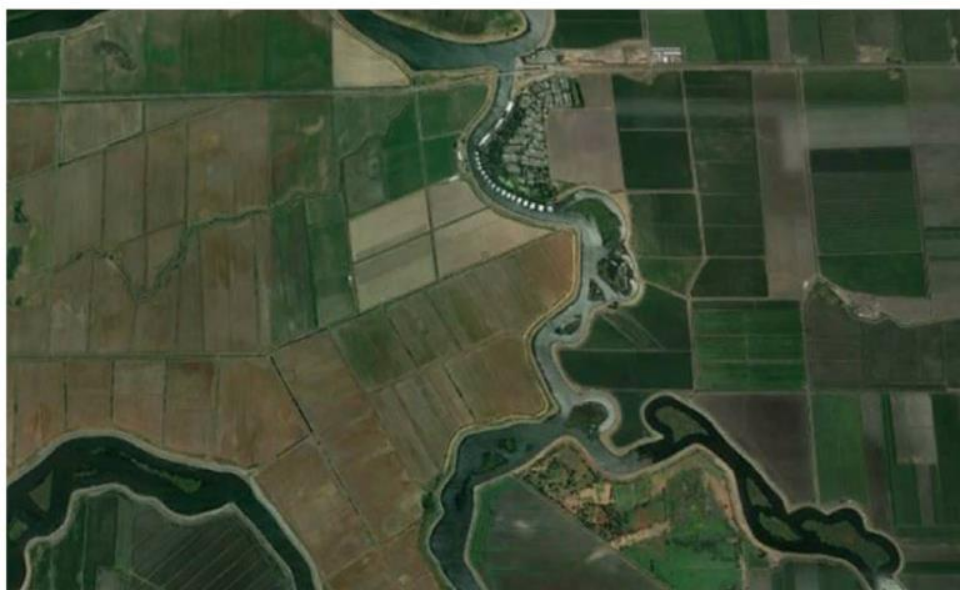
100 ha = maximum Black
Rail density

500 ha = full channel
network

PAST



PRESENT



FUTURE



Illustration by Yiping Lu (UC Berkeley)

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www.sfei.org/projects/delta-landscapes

SFEI Project Team: *Julie Beagle, Letitia Grenier, Robin Grossinger, April Robinson, Sam Safran, and Ruth Askevold (design)*

CDFW: *Daniel Burmester, Carl Wilcox, Dave Zezulak, Kevin Fleming*

DSP: *Peter Goodwin, Chris Enright, Anke Mueller-Solger, Cliff Dahm, Rainer Hoenicke*

Landscape Interpretation Team Science Advisors

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